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Research Article

Development of lip protrusion in trahira, *Hoplias malabaricus* (Bloch, 1794), associated with aquatic surface respiration

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Abstract

The histological organization of labial development of trahira *Hoplias malabaricus* found in a drying pool was compared with normal fish from a similar environment. It was found that labial development was not associated with any visible histological change in key tissues. We hypothesize that the fish had been recently trapped in the pool (for a few weeks) and did not have the time to respond to the stressful conditions, and that the labial development was not associated with increase in respiration surface area but rather may serve to channel oxygen-rich surface water more efficiently into the mouth chamber.

Key words: Drylands, fish physiology, hypoxia, intermittent streams

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Introduction

Intermittent streams of dryland regions are renowned for their extreme variations in water levels and harshness of environmental conditions for the fish fauna. These harsh conditions are created during extended dry periods when the river dries out and only stagnant pools are left in the dry riverbed (Vorste et al. 2020). This leads to high water temperatures, low dissolved oxygen, high rates of organic matter decomposition, algal blooms, high parasitism rates, and limited space, among many other stressful factors. Fish are, therefore, required to adapt to such harsh and variable systems, presenting populational and individual strategies to respond to the often unpredictable conditions (Medeiros et al. 2024).

Among the individual strategies that fish can present are the movement to deeper and cooler areas of the pool and accessory respiration with the aid of behavioral or physiological responses to low levels of dissolved oxygen in the water (Zhu et al. 2013; Lima et al. 2025). Fish tend to move less

and take oxygen in the superficial layers of the water, where there are higher rates of diffusion between the atmospheric and aquatic gases (Rantin et al. 1993; Soares et al. 2006; Neto et al. 2020).

Among the physiological responses, fish can reduce cardiac frequency (Rantin et al. 1993), perform anaerobic respiration, develop highly vascularized structures in their mouth (such as barbels), or develop protruding lips to increase surface contact with the water and enhance oxygen uptake (Neto et al. 2020). Braz-Mota and Almeida-Val (2021) point out that, under normoxic conditions, the gill can compensate for its small surface area with a thin water-blood barrier, enhancing gas exchange. Histologically, it shows a well-defined apical crypt of the mitochondria-rich cells and subapical microvesicles. In hypoxia, gill oxygen uptake declines as mitochondria-rich cells are covered and displaced by pavement cells, reducing ion transport and energy costs. Pavement cells, therefore, expand their surface area through increased microridges, thickening the blood-water barrier. Other responses include the increase in the frequency of opercular beats to move more water over the gills or an increased metabolism in organs like the liver and muscle tissues (Winemiller 1989; Soares et al. 2006).

Even hardy fish species such as *H. malabaricus*, also known as trahira or wolf fish, has developed a range of strategies to cope with harsh and stressful situations, ranging from changes in heartbeat rates to muscle tissue absorption (Rantin and Johansen 1984; Rantin et al. 1993; Rios et al. 2009; Rocha 2011).

In the present study, we report another possible response of trahira to environmental stress, that is, the development of a dermal lip edema, with the appearance of a protrusion or protuberance (Fig. 1). Our objective is to evaluate three fish that were found with such structures in natural conditions and compare them with normal fish from a similar environment. Comparisons are performed based on the morphological and histological characteristics of key body tissues. We investigate the histological organization of these tissues of *H. malabaricus* presenting labial protuberance and compare them with specimens that did not develop these characteristics. It is important to highlight that these fish were not actively sought and sampled but were found by chance in a drying pool during a fieldwork activity. In this sense, this is a case study report and not an experiment or research based on a planned study design.

Materials and methods

The collection of specimens took place in November 2020, during the dry season. A total of three specimens from the sampled site in the Brazilian semiarid region was examined (4°26'55.707"S, 40°02'55.161"W). These were the only trahira specimens found inhabiting the study pool. These specimens were compared with three specimens previously collected in November of 2010, which did not present lip protuberance, from other temporary pools in the same region under normal temperature and dissolved oxygen conditions. All specimens were fixed in 10% formalin for approximately two weeks and subsequently stored in 70% ethanol. Specimens were examined, and the morphological properties of their external anatomy and internal organs were measured. Fish stomachs were evaluated for their content and degree of fullness (Medeiros and Arthington 2008). The gonadal development stages

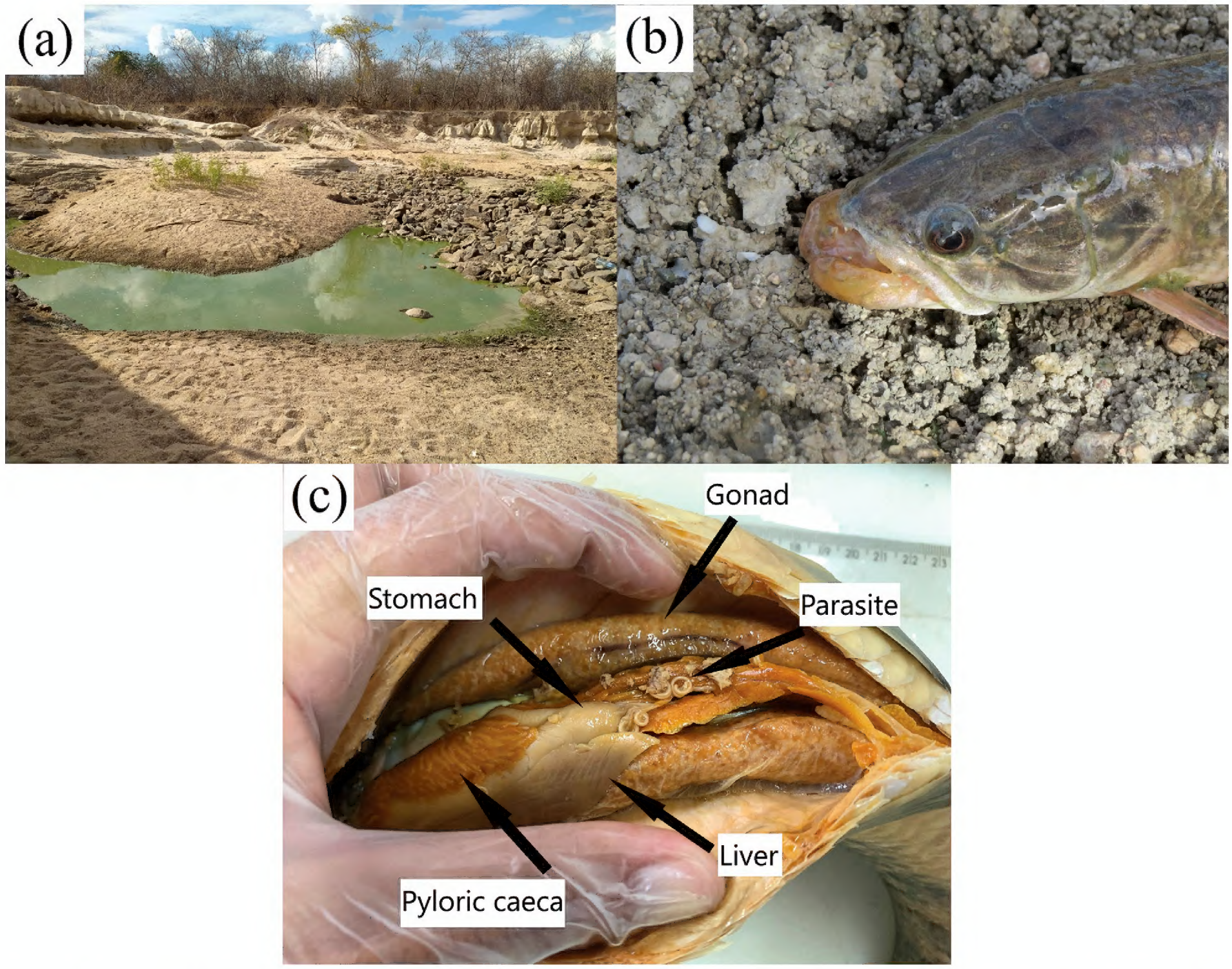

Figure 1. a Temporary pool in an intermittent stream where fish with lip development were found (04°26'55.707"S, 40°02'55.161"W) **b** specimen of *Hoplias malabaricus* displaying the lip protuberance **c** internal morphology of a female *H. malabaricus* showing pronounced lip development.

for males and females were investigated using two methods: macroscopic examination of the consistence and volume of the reproductive system and microscopic examination through histological analysis (Vazzoler 1996; Marques et al. 2000). Gonadal development was classified as stage I (immature or pre-vitellogenic), stage II (ripening or in vitellogenesis), stage III (mature or complete vitellogenesis) and stage IV (spawned) for females; and as stage I (immature), stage II (maturing) and stage III (mature) for males (adapted from Vazzoler 1996; Marques et al. 2000; Brown-Peterson et al. 2011; Diniz et al. 2023) (Fig. 2). The gonadosomatic index (GSI) was calculated as the gonad weight divided by the body weight (Vazzoler 1996). Organs and tissues of interest (gill, liver, dorsal muscle, heart, gonad, and lip) were removed and measured for length and weight on a precision scale. These tissues were used for histological analysis. Samples were processed for histological analysis using Hematoxylin and Eosin staining, and tissue sections were submitted to high-resolution scanning (MoticEasyScan Pro 6, Motic Inc., Richmond, BC, CAN). Fish were collected under the Brazilian Institute for the Environment and Renewable Natural Resources ICMBIO/SISBIO licenses no. 23348-1 from June 15 of 2010, and 56416-4 from January 17 of 2019.

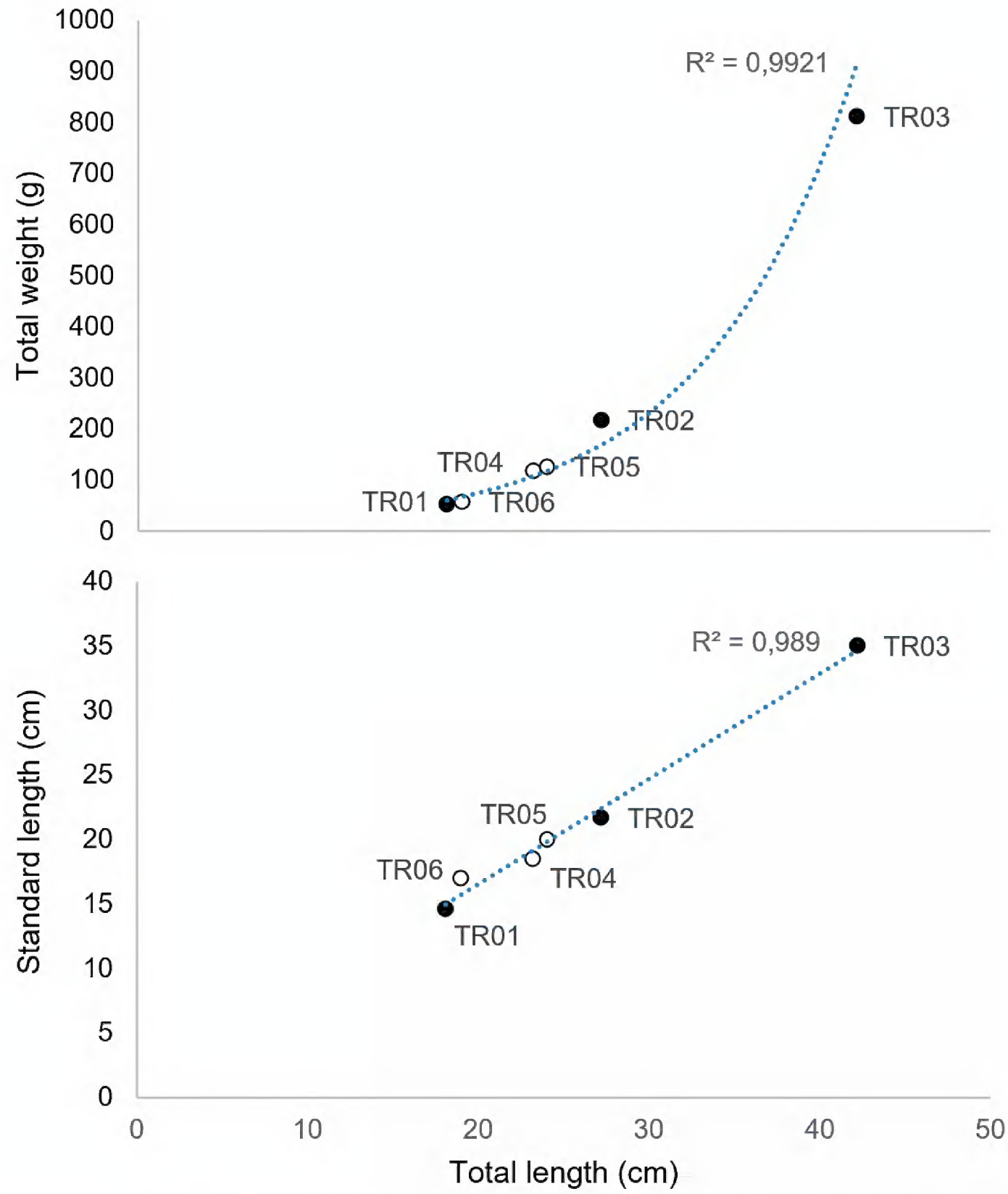

Figure 2. Relationship between total weight (g) and total length (cm) of *Hoplias malabaricus* specimens. Black circle = presence of lip development; White circle = absence of lip development. Trahira specimens as per Table 1.

Table 1. Morphological information of *Hoplias malabaricus* specimens. Total length (TL), Standard length (SL), Total weight (TW), Sex, Lip protuberance (LP) and Gonadosomatic Index (GSI).

Specimen	TL (cm)	SL (cm)	TW (g)	Sex	LP	GSI
TR01	18.1	14.6	53.2	male	present	0.90
TR02	27.2	21.7	217.6	male	present	0.07
TR03	42.2	35.0	812.0	female	present	2.66
TR04	23.2	18.5	117.7	male	absent	1.69
TR05	24.0	20.0	126.4	female	absent	2.61
TR06	19.0	17.0	58.3	female	absent	0.77

Results

The size of the specimens ranged from 18.1 to 42.2 cm in total length (TL), with females exhibiting a higher GSI (0.07 to 1.69 for males and 0.77 to 2.66 for females) (Table 1), which is expected under conditions indicative of reproductive

activity. The length-weight relationship of the study fish (Fig. 2) shows an exponential growth curve with a proportional growth for all specimens, as expected under normal fish growth conditions. This is supported by the relationship between the weight and length of the gonads (R^2 = 0.989), where larger gonads were observed along with higher weights. Analysis of stomach content showed that all specimens had empty stomachs.

Histological analysis of the gonads (Fig. 3) of the study specimens demonstrate that they were in similar stages of gonadal development. All females presented maturation stages ranging from II and III, without any indication of gonadal stress, such as early spawning, oocyte reabsorption, or filamentous structures indicating signs of hemorrhagic vascularization. Some variation was observed, with one of the females presenting gonads containing a minority of young oocytes, and the majority of oocytes were in maturation, with the presence of lipidic vitellogenesis and germinal pores in the oocytes of stage II. In another specimen, we observed reserve stock oocytes and oocytes in the final maturation process with signs of lipidic vitellogenesis and germinal pores. Most of the oocytes in another specimen were in the initial stages of maturation, with the presence of reserve stock oocytes and complete vitellogenesis of these oocytes. Regardless, all analyzed gonads revealed healthy developmental stages, indicating the integrity of the maturation process in females. Similar results were observed in males (Fig. 3), with gonads exhibiting histological characteristics consistent with advanced maturation stages, mainly stage II. The integrity of gonadal tissues was evident in all analyzed males, without signs of gonadal stress.

Evaluation of the microscopic structure of the gills did not indicate compromise in these organs, their structure and external morphology, between specimens that presented or did not present lip protuberance. Histological slides of the gills (Fig. 3) show important histological structures in comparison between specimens that presented and did not present a labial protuberance. It is possible to observe the existence of primary lamellae in a darker coloration and cartilage with a lighter coloration. Mucous cells, pillar cells, chloride cells, lamellar epithelial cells, marginal blood channels, and lamellar venous sinuses are evident (Machado 1999). All these characteristics were observed in specimens with lip protuberance and in those without these structures and are consistent with gills belonging to healthy fish.

Microscopic evaluation of the other tissues of interest, liver, dorsal muscle and heart, showed no signs of damage. The liver and muscle tissues (Fig. 3) showed indication of neither increased metabolism nor muscle absorption when compared between healthy specimens and those with lip development. A hepatic lobule is not clearly visible in Fig. 3, but the hepatocytes are visible as well as portal areas and connective tissue. In the muscle samples, the muscle fibers can be seen as elongated cells grouped into fascicles, and at closer inspection, a cross-banded pattern along its length, with flattened peripheral nuclei.

The endocardium lines and the atrial chamber can be seen in the heart, with bundles of cardiac muscle cells and loose connective tissue. Arteriole and venule were observable with the blood cells filling their lumina (Ovalle and Nahirney 2021). Macroscopic and microscopic analyses of the heart also showed dimensions and histological organization comparable between healthy specimens and those that developed the lip protuberance.

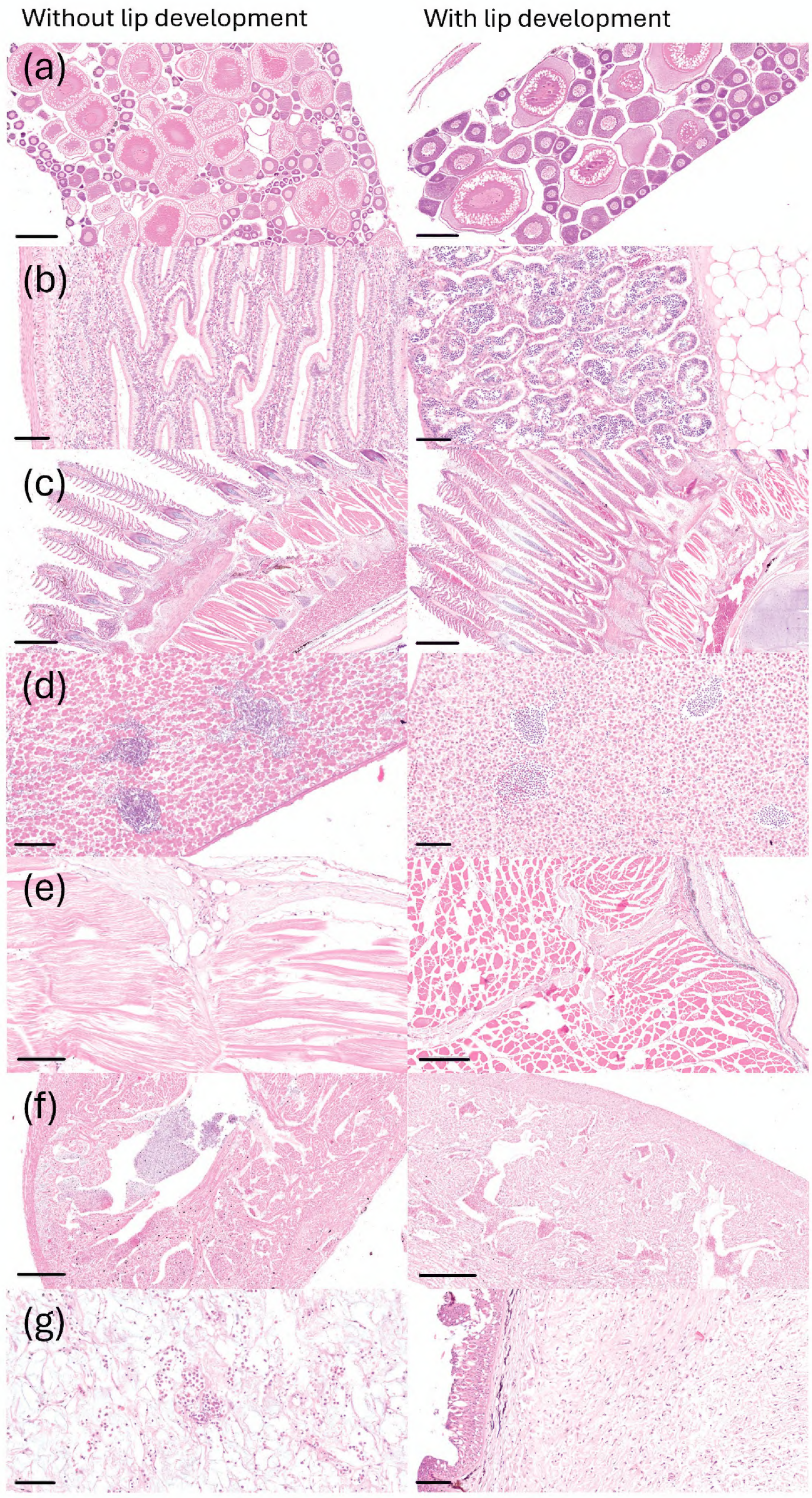

Figure 3. Representative histological sections of key organs and tissues of interest of *Hoplias malabaricus* specimens without lip development (left) and with lip development (right) **a** female gonad (500 and 200 µm) **b** male gonad (80 and 100 µm) **c** gill (300 and 400 µm) **d** liver (60 and 70 µm) **e** dorsal muscle (90 and 200 µm) **f** heart muscle (400 µm) **g** lip (70 and 80 µm). Black bars indicate the scale of magnification left and right respectively.

In the images of the lip (Fig. 3), a loose and edematous connective tissue is observable in the specimens without labial protuberance. In the specimen with labial protuberance, the connective tissue exhibits thicker collagen fibers, predominantly organized in a dense manner. Based on these images, it can be inferred that there is a higher level of collagenization in the connective tissue of the lip of fish that developed labial protuberance. It is important to point out that the image of the specimen without labial protuberance does not show the epithelial lining, as opposed to the image of the fish with protuberance. Nonetheless, this difference in connective tissue density likely results from the area where the image was captured and does not indicate vascularization for increased oxygen absorption.

Discussion

The results for fish size, GSI and length-weight relationship indicate increased production of oocytes and spermatozoa with increasing weight relative to length (Marques et al. 2000). Fish in periods of reproductive inactivity have elongated gonads relative to their body but with low weight due to the absence of reproductive cells (Vazzoler 1996), the opposite being perceivable in this study. Furthermore, the GSI shows that females had higher values than males, which is expected under conditions indicative of reproductive activity.

The higher stages of gonadal development are likely leading to the absence of stomach content of the study fish, since fish are known to stop feeding prior to spawning to allow for larger gonads and therefore hold more eggs in the abdominal cavity. In fish, the seasonal cycle of nutritional reserves, such as fat accumulation, follows a pattern associated with reproduction. During reproduction, fish reduce feeding activity and use energy reserves stored in fat for gonadal maturation. The pyloric caeca were well developed, one of its functions being the expansion of the intestinal absorptive surface area (Buddington and Diamond 1986). Even though parasitic occurrence was recorded in some of the study specimens (probably from the nematoid family Anisakidae, Rodrigues et al. 2017) (Fig. 1), there was no indication that this was a reflection of environmental stress, given the overall state of fish health and since *Hoplias* commonly harbor a diverse parasite fauna (Rocha 2011; Reis et al. 2017).

The lack of evidence of histological differences between fish with or without lip development, based on the analyses of the gills, liver, heart and muscle, was not expected based on the literature about the responses of fish to environmental stress and the damage that stressful conditions can cause to these tissues (Gayão et al. 2013). Overall, all these tissues seem normal when compared across all study fish specimens, except for some cases where we observed precipitated formalin, resulting from the process of fixation with formalin for an extended period prior to Hematoxylin and Eosin staining. Even with thorough washing of the material, sediment remained on some slides.

Braz-Mota and Almeida-Val (2021) point out that, under hypoxic conditions, pavement cells of the gills expand their surface area through increased microridges, thickening the blood-water barrier. We were unable to see those structures with our methodology, but in situ measuring indicates low levels of oxygen in the pool where fish with lip protrusion were collected and normal levels of oxygen where fish without lip protrusion were collected. Additionally, the development of dermal

lip protrusions in this study did not seem to be associated with other deeper physiological responses, such as the function of hemosiderin (a perivascular pigment representing areas of hemorrhagic extravasation), which is mentioned in relation to the rapid formation of barbels or dermal edema in other species (Neto et al. 2020). They were not highly vascularized as would be expected if they were indicative of another surface area for oxygen exchange with the medium (Scarabotti et al. 2011). Although the development of dermal protrusions might have resulted from rapid changes occurring in a few hours for the development of these large structures, they did not present histologically complex features, lacking innervations and developed vascularization as would be expected. Additionally, from the histological standpoint, there was no visible influence on the liver function.

One can hypothesize that the collected trahiras had been recently trapped in the study pool (for a few weeks) after the stream dried up and did not have time yet to respond to the likely stressful conditions to which they were subjected. Intermittent streams may have a very short period of flooding when fish disperse throughout the waterscape but are subsequently trapped in temporary or ephemeral pools in the dry river bed (Terra et al. 2021). Responses to the consequent stressful conditions would be the reabsorption of germ cells, burning of muscle tissues and liver or heart damage (Rantin and Johansen 1984; Rantin et al. 1993; Rios et al. 2009). None of these were observed based on histological analyses.

We propose, for the observed development of the lip protuberance in the study fish, that its function is not associated with gas exchange with the atmospheric air per se but to channel more effectively the flow of more oxygenated water from the pool surface to the mouth chamber and thus increase oxygen intake through the already established gill systems. This is supported by the healthy condition of the gills in fish with lip protuberances compared to those without them. But this proposition remains as a hypothesis to be tested.

Overall, our results suggest that, under the conditions of the present study, specimens of *H. malabaricus* exhibited normal and healthy development in both males and females. The absence of indicators of tissue stress, particularly the gonads, is a positive indication of the adaptability of the species to their environment. However, future studies should focus on investigating environmental stress in experimental conditions for a more comprehensive understanding of the physiological responses of this species to environmental change.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

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Author contributions

Conceptualization of the study was carried out by TPAR and ESFM. The necessary resources for the research were provided by JMF, SYLC, and MMSM. The methodology was developed by ESFM and MMSM, while laboratory work was handled by ESFM. Fieldwork was conducted by TPAR, SYLC, and JMF. The original draft was written by ESFM and MMSM, and the review and editing of the text were overseen by ESFM.

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Data availability

The datasets for the current study will be available from the corresponding author on reasonable request.

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